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PATENT SPECIFICATION

(11) 1 546 926

(21) Application No. 38940/76 (22) Filed 20 Sept. 1976
(31) Convention Application No. 2 551 584
(32) Filed 17 Nov. 1975 in
(33) Fed. Rep. of Germany (DE)
(44) Complete Specification published 31 May 1979
(51) INT CL² G01N 23/06
(52) Index at acceptance
H4F D18X D30K D56X D83B D83X L
G1G 1A 2 4C RE

(19) THE PATENT OFFICE LONDON

(54) X-RAY APPARATUS

(71) We, SIEMENS AKTIENGESELLSCHAFT, a German company, of Berlin and Munich, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to x-ray apparatus operable to provide measures of the values that a radiation-influencing parameter of an irradiated body respectively has at different regions in a given body plane. The invention is, for example, applicable to x-ray apparatus with which the density distribution in a given body plane can be obtained and visually represented in numerical or analogue form so as to provide an image of the body plane.

An x-ray apparatus for providing an image of a planar layer of a body may comprise an x-ray measuring arrangement with an x-ray source that produces an x-ray beam, penetrating the body, whose cross-sectional extent perpendicular to the layer plane defines the layer thickness, and with a radiation receiver which determines the beam intensity downstream of the body, the apparatus also comprising drive means for producing rotary movement of the x-ray measuring arrangement relative to the body, as well as signal processing means for using the output signals of the radiation receiver to provide the required image.

To obtain the image, the rotary movement of the measuring arrangement can be a succession of small equidistant angular steps alternately performed with displacement of the measuring arrangement along a straight line perpendicular to the central ray of the x-ray beam. In this case, a single radiation detector is sufficient as radiation receiver. However, it is possible to dispense with linear displacement of the measuring arrangement if the radiation receiver is composed of a plurality of radiation detectors and if the x-ray beam is fan-shaped and strikes all the detectors simultaneously. In this case, the detectors simultaneously provide respective output signals which can be simultaneously processed.

An x-ray apparatus of this type for producing an image of a planar body-layer is described in German Offenlegungsschrift 1,941,433. The path which the x-ray beam covers through the body being examined is in this case, on account of the shape of most bodies of interest, longer in the middle of the body than in the peripheral regions. Assuming constant body density, then output signals of different magnitudes are provided by the radiation receiver for different ray paths, which makes signal processing difficult. Further, when using a polychromatic x-ray spectrum, as is generally the case in medical x-ray diagnostic apparatus, the varying attenuation of the x-ray beam due to differences of density within the interior of the body leads to a variation in spectral composition of the radiation in dependence upon the attenuation. This renders image reproduction more difficult

In order to compensate for attenuation differences between the central and peripheral regions caused as a result of the shape of a body to be examined, the body can be positioned in an externally rectangular block made of a material with radiation absorption properties similar to those of the body being examined. The positioning of the body in such a block, particularly in the case of a human body, may be inconvenient and time-consuming. Further, the provision of such a block means increased technical outlay.

It is accordingly desirable to provide an x-ray apparatus with which it is possible, when investigating the density distribution in a chosen body plane, to compensate for the varying spectral composition that polychromatic radiation has after passing through an inhomogeneous body of varying thickness on account of the fact that different ray paths for which intensity measurements are made are of different lengths.

According to the present invention, there is provided x-ray apparatus comprising an x-ray source and an x-ray intensity measuring device which are arranged so as to permit the beam

intensity downstream of a body irradiated by the source to be measured for each of a multiplicity of ray paths that extend through the body in the same body plane, the apparatus including signal processing means adapted to process electrical output signals from the intensity measuring device so as to provide measures of the values that a radiation-influencing parameter of the body respectively has at different regions in the said body plane, and ultrasonic means for measuring the extent, through the body, of each ray path so as to provide electrical correction signals for the signal processing means.

The x-ray source and the x-ray intensity measuring device may be parts of a unit which is rotatable about an axis of rotation perpendicular to the body plane in which the body under investigation is irradiated, and there may be drive means for rotating this unit, relative to the body under investigation, through successive angular steps about the axis of rotation.

The ultrasonic means may comprise an ultrasonic emitter/receiver head (i.e. a head incorporating an ultrasonic transducer arrangement for emitting and receiving ultrasonic radiation) coupled with the rotatable unit in such fashion that the distance, as measured parallel to a predetermined axis of the unit, between the emitter/receiver head and the axis of rotation of the unit remains constant. Thus, the emitter/receiver head can be fixed to the unit so as to direct radiation onto the body parallel to the predetermined axis (for example, the central axis of the x-ray beam). Then, when the emitter/receiver head is rotated or displaced, relative to the body, with the unit to which it is fixed, the distance, as measured parallel to the predetermined axis, between the emitter/receiver head and the particular body surface on which the ultrasonic radiation is incident at any time varies in accordance with the local body thickness.

Alternatively, the ultrasonic means may comprise a displaceably mounted ultrasonic emitter/receiver head arranged to direct ultrasonic radiation onto the body under investigation, a drive device for displacing the emitter/receiver. head, and automatic control means operable to control the drive device in such fashion that the distance, as measured parallel to a predetermined axis of the apparatus, between the emitter/receiver head and the particular body surface on which the ultrasonic radiation is incident at any time is maintained constant. The required correction signals for the signal processing means can then be derived from the automatic control means. As in the previous case, the x-ray source and the intensity measuring device may be parts of a unit which is rotatable relative to the body about an axis of rotation perpendicular to the body plane being irradiated. However, with the emitter/receiver head for example arranged to direct ultrasonic radiation onto the body parallel to the predetermined axis (for example, the central axis of the x-ray beam), the distance as measured parallel to this axis, between the emitter/receiver head and the axis of rotation of the unit will vary in accordance with the body's shape as the unit is rotated or displaced relative to the body.

It will be appreciated that x-ray apparatus embodying the present invention may include a display device which, under the control of signals from the signal processing means, produces a visual image in analogue or numerical form of the irradiated body plane.

For a better understanding of the invention and to show how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawing, which diagrammatically illustrates one form of x-ray apparatus embodying the present invention.

The illustrated x-ray apparatus comprises an x-ray source in the form of an x-ray tube 1 which is connected by means of a bar structure 2 to an x-ray detector 3 suitable for intensity measurement. The x-ray tube 1 produces a narrow radiation beam 4 which is directed through a body 5 under investigation towards the detector 3. The x-ray tube 1, the bar structure 2 and the detector 3 are displaceable as a unit, transversely to the central axis of the radiation beam 4, along a pair of slide rails 6 parallel to the double headed arrow 7. For a particular orientation of the body 5 to the unit 1, 2, 3, therefore, the beam intensity downstream of the body can be measured with the detector 3 for each of a set of mutually parallel ray paths all lying in the same body plane. The combination of the x-ray tube 1, the bar structure 2, the detector 3 and the slide rails 6 is rotatable as a unit about an axis of rotation 8 which passes approximately centrally through the body 5 in a direction perpendicular to the body plane through which the radiation beam 4 is swept by displacement of the unit 1, 2, 3 along the rails 6.

After obtaining intensity measurements for one set of mutually parallel ray paths through the body 5, the unit 1, 2, 3, 6 is rotated about the axis 8 through a small angle, for example a few degrees, relative to the body 5, and the unit 1, 2, 3 is then displaced along the rails 6 so that the beam 4 sweeps through the whole of the body 5 and a set of intensity measurements can thus be obtained for a second set of mutually parallel ray paths through the body. After this, a further rotation operation is performed, followed by a further displacement operation, and so on, until the unit 1, 2, 3, 6 has been rotated through a total of 360° relative to the body 5. The angular steps through which the unit 1, 2, 3, 6 is successively

rotated are all of the same size. The detector 3 provides electrical output signals indicative of the intensities, downstream of the body 5, for the ray paths along which the body is irradiated, and these signals are supplied to signal processing means 9. The signal processing means 9 use these signals to provide measures of the values that a radiation-influencing parameter of the body 5 respectively has at different regions in the irradiated body plane, for example the local absorption coefficients or the local density values in the plane. These measures are applied in the form of electrical signals to a television monitor 10 which provides an image of the irradiated body plane. The signal processing means 9 may contain a computer which produces the image-forming signals for the television monitor 10 in accordance with the method of calculation described in "Journal of Applied Physics", Vol. 34, No. 9, pages 2722 onwards, and Vol. 35, No. 10, pages 2908 onwards, by A. M. Cormack. Underlying the method of calculation described in that publication is the assumption that the x-radiation employed is monochromatic. In practice, it is difficult to achieve monochromatic radiation, and so the aim is to be able to work with the polychromatic spectrum derived from a normal commercial x-ray tube, if possible. The use of such a bremsstrahlung spectrum, however, leads to alteration of spectral composition in dependence on radiation attenuation. In the case of strong attenuation, the spectrum is hardened in relation to its original composition. Harder radiation has a greater penetration capacity than soft radiation, so that without the correction procedure described hereinafter, the method of calculation will lead to inaccurate results because of the different lengths of the different ray paths along which the body 5 is irradiated, which means that the image produced on the television monitor 10 will be inaccurate. For example, features may be blurred, or total adulterations or misleading representations due to image faults may occur.

To compensate for the differing lengths of the different ray paths along which the body 5 is irradiated by the beam 4, correction signals are applied to the signal processing means 9 from ultrasonic means adapted to measure the extent, through the body 5, of each ray path involved. The ultrasonic means comprise an ultrasonic emitter/receiver head 11 containing an ultrasonic transmitter and an ultrasonic receiver. The ultrasonic transmitter directs a beam 13 of ultrasonic radiation onto the body 5, and this beam is reflected at the body surface and picked up by the ultrasonic receiver. The ultrasonic means also comprise a measuring arrangement 14 which serves to determine the distance between the emitter/receiver head 11 and the body surface from the time which elapses between emission of an ultrasonic signal and detection of the signal following its reflection at the body surface. For each ray path along which the body 5 is irradiated, the measuring arrangement 14 produces a signal indicative of this distance. The signals obtained are supplied to a correction device 15 which so controls the signal processing means 9 that image errors due to the differing path lengths of different ray paths are avoided. If the distance between the x-ray tube 1 and the body surface is ascertained for each orientation of the unit 1, 2, 3, 6, the path lengths of the various ray paths along which the body is irradiated can also be ascertained.

Instead of rotating the unit 1, 2, 3, 6 through a total angle of 360°, the unit may be rotated through only 180°. In this case, however, it is expedient to provide two ultrasonic emitter/receiver heads respectively arranged to scan opposite sides of the body. One head then measures the distance between the x-ray tube 1 and the body surface facing the tube, and the other head measures the distance between the detector 3 and the body surface facing the detector. A single ultrasonic emitter/receiver is adequate, however, if the body 5 can be presumed to have right-left symmetry.

The ultrasonic distance measurement is mechanically simplest if, as illustrated in the drawing, the ultrasonic emitter/receiver head is arranged at a fixed distance (as measured parallel to the central axis of the beam 4) from the axis of rotation 8 of the unit 1, 2, 3, 6. Acoustically more favourable, however, is an arrangement in which the contour of the body 5 is scanned by means of a displaceably mounted ultrasonic emitter/receiver head which is automatically controlled so as to remain at a constant distance (as measured parallel to a predetermined axis, for example the central axis of the x-ray beam 4) from the body surface onto which ultrasonic radiation is directed by the head. This distance can then be so selected that the focus of the ultrasonic field is located at the body surface. Moreover, the ultrasonic echoes then have constant amplitudes. In this case, the extent to which the ultrasonic emitter/receiver head must be displaced in order to maintain the abovementioned distance constant is a measure of the path length of the ray path along which the body 5 is being irradiated by the x-ray beam 4 at any time.

While the illustrated embodiment of the invention makes use of linear displacement of the unit 1, 2, 3 parallel to the double arrow 7 for each selected orientation of the unit relative to the body 5, such linear displacement can be dispensed with if the detector 3 is replaced by a receiver composed of a number of detectors on which a fan-shaped

beam of x-radiation impinges simultaneously, i.e. if a multi-channel measuring arrangement is employed.

WHAT WE CLAIM IS:—

1. X-ray apparatus comprising an x-ray source and an x-ray intensity measuring device which are arranged so as to permit the beam intensity downstream of a body irradiated by the source to be measured for each of a multiplicity of ray paths that extend through the body in the same body plane, the apparatus including signal processing means adapted to process electrical output signals from the intensity of measuring device so as to provide measures of the values that a radiation-influencing parameter of the body respectively has at different regions in the said body plane, and ultrasonic means for measuring the extent, through the body, of each ray path so as to provide electrical correction signals for the signal processing means.

2. Apparatus as claimed in claim 1, wherein the x-ray source and the x-ray intensity measuring device are parts of a unit which is rotatable about an axis of rotation perpendicular to the said body plane.

3. Apparatus as claimed in claim 2, including drive means for rotating the said unit, relative to the body, through successive angular steps about the said axis of rotation.

4. Apparatus as claimed in claim 2 or 3, wherein the said ultrasonic means comprise an ultrasonic emitter/receiver head coupled to the said unit in such fashion that the distance, as measured parallel to a predetermined axis of the unit between the emitter/receiver head and the said axis of rotation remains constant in use of the apparatus.

5. Apparatus as claimed in claim 1, 2 or 3, wherein the said ultrasonic means comprise a displaceably mounted ultrasonic emitter/receiver head arranged to direct ultrasonic radiation onto the body, a drive device for displacing the emitter/receiver head, and automatic control means operable to control the drive device in such fashion that the distance, as measured parallel to a predetermined axis of the apparatus, between the emitter/receiver head and the body surface on which the ultrasonic radiation is incident is maintained constant, the said correction signals being derived from the automatic control means.

6. Apparatus as claimed in any preceding claim, including a display device operable to produce a visual image of the said body plane from signals provided by the said signal processing means.

7. X-ray apparatus substantially as hereinbefore described with reference to the accompanying drawing.

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Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1979.
Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1546926 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*